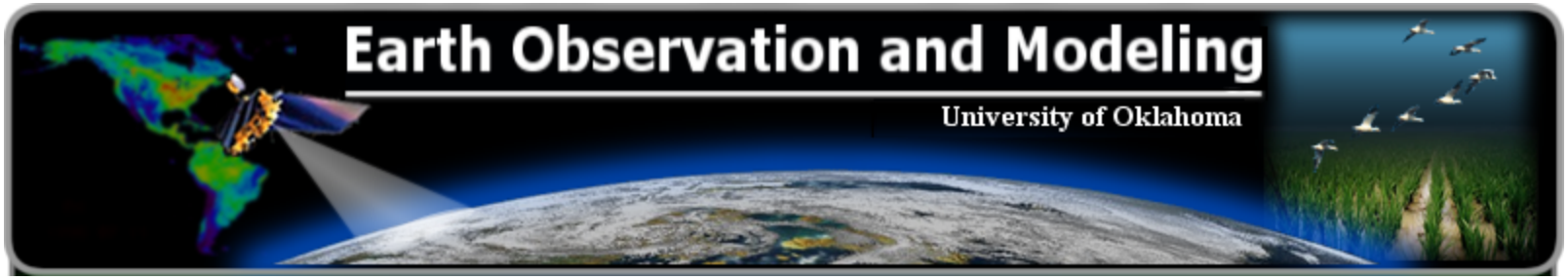

Integrating Earth Observation and Satellite Telemetry of Wild Birds for Decision Support System of Avian Influenza

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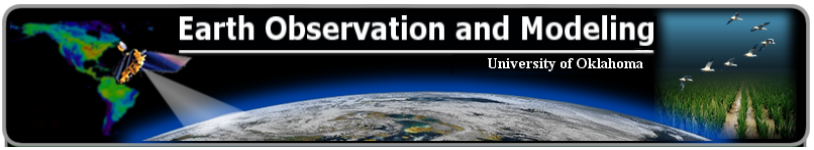
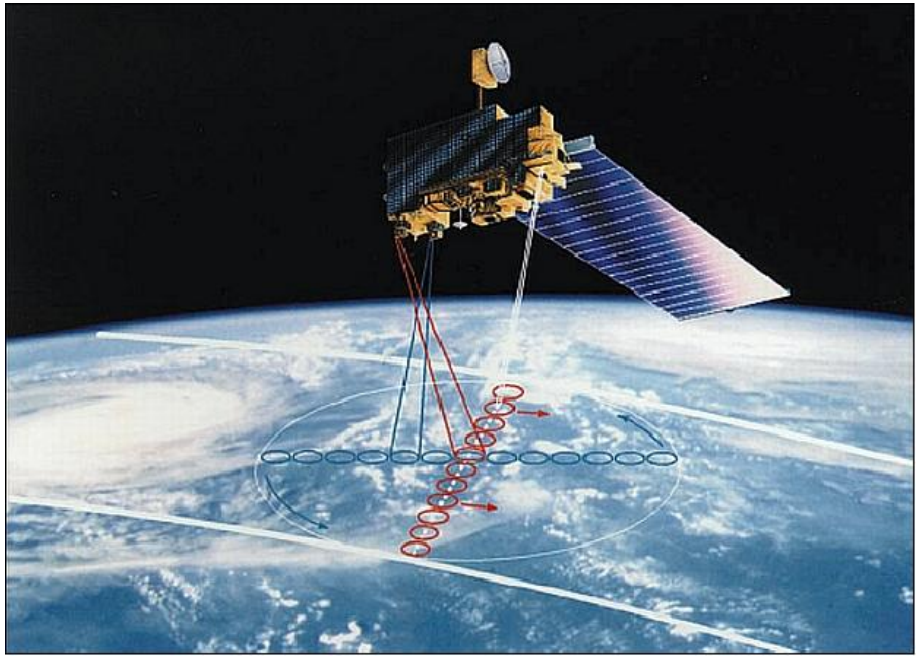
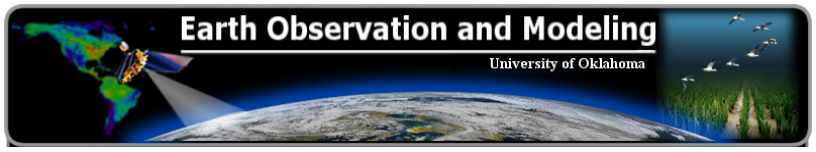
NASA Health and Air Quality Application Program Review
September 24-26, 2013, St. Paul, Minnesota, USA



Outline of the Presentation

1. Project overview, as it approaches to end in 12/2013
2. Project accomplishment and deliverable
3. Broader impact of the project
4. What is next?





Project Overview

Research Team

University of Oklahoma
Nyambayar Batabayar, Delong Zhao, Pavel Dorovskoy, Michael Menarguez, Satya Prabhala

USGS
John Takekawa, Diann Prosser

FAO/UN
Scott Newman, Jan Slingenbergh

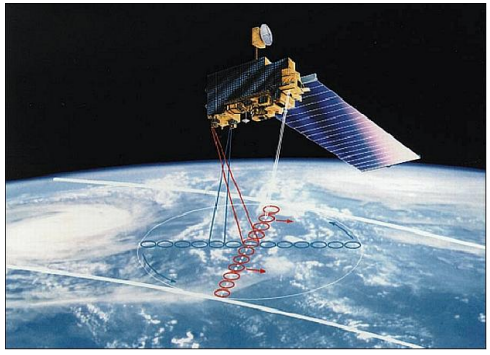
Belgium
Marius Gilbert

Many in-country collaborators in China, Mongolia, Bangladesh and India

Relevant projects that provide data

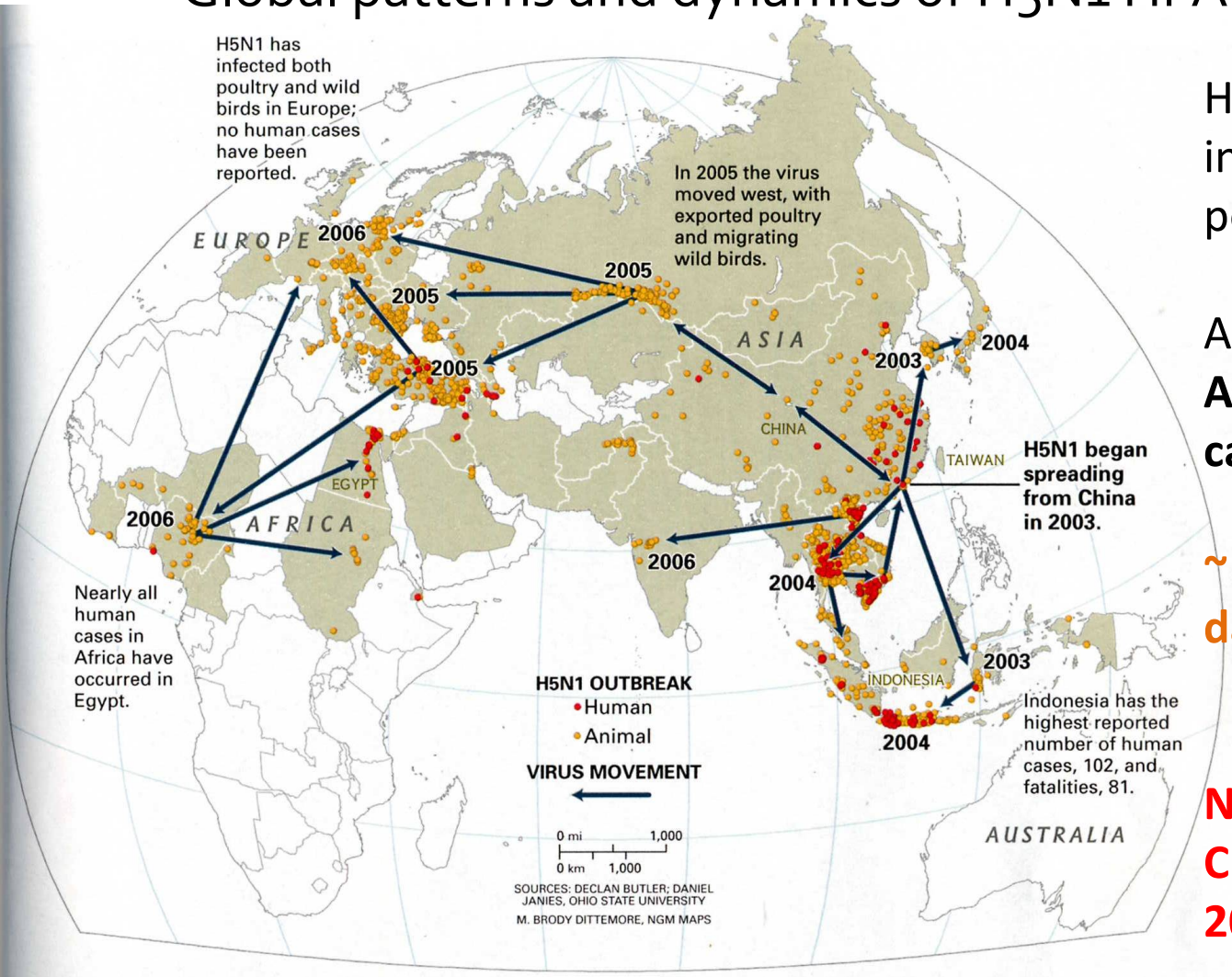
This NASA Public Health Feasibility project is built upon our previous and ongoing projects from the following funding agencies:

NASA Land Use and Land Cover Change
National Institutes of Health
National Science Foundation
USGS
FAO



Why we study avian influenza A (H5N1)?

Global patterns and dynamics of H5N1 HPAI (2003 – 2006)



MARCH OF THE BIRD FLU *The avian influenza strain H5N1 is the world's top pandemic threat. Starting in China, in 2003 it began spreading through other parts of Asia and by 2006 had shown up in Europe and Africa. Experts fear that H5N1, which has killed fewer than 200 people, may mutate to a virulent form able to wipe out millions.*

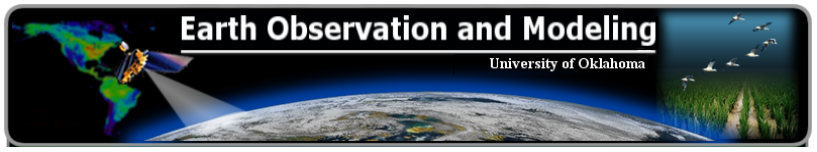
H5N1 has continued to infect poultry, birds and people.

As of August 29, 2013, **A total of 637 human cases and 378 deaths**

~ $20 billion of economic damage

New H5N1 clade 2.3.2.1 in China and Vietnam in 2011

From David Quammen, How animals and humans exchange disease -- Deadly Contact, National Geographic, 10/2007



Role of wild birds in avian influenza A (H5N1)

H5N1 outbreak in wild birds, Qinghai Lake, Tibetan Plateau, China, 5/2005

BREVIA

Highly Pathogenic H5N1 Influenza Virus Infection in Migratory Birds

J. Liu,[1*†] H. Xiao,[2,4*] F. Lei,[3*] Q. Zhu,[5] K. Qin,[1] X.-w. Zhang,[6] X.-l. Zhang,[1] D. Zhao,[1] G. Wang,[2,4] Y. Feng,[2,4] J. Ma,[2] W. Liu,[2] J. Wang,[6] G. F. Gao[2†]

Avian influenza virus (AIV) involving at least three subtypes, H5, H7, and H9, has emerged as an important pathogen in the poultry industry and is of major current global health concern (*1*). The first case report of chicken-to-human transmission was in Hong Kong in 1997 (*2*); since 2003, H5N1, a highly pathogenic AIV, has emerged in 10 Asian countries, including Thailand, Vietnam, and China (Fig. 1), and has claimed at least 53 human lives. Until recently, migratory waterfowl seemed to be exempt from widespread infection, although sporadic cases were recorded (*3*). Here we describe an outbreak of highly pathogenic H5N1 infection among waterfowl in Lake Qinghaihu, Gangcha County, Qinghai Province, in western China (Fig. 1).

On 4 May 2005, a few birds were found dead on Bird Island, and by the end of June more than a thousand birds were affected. This lake is one of the most important breeding locations for migratory birds that overwinter in Southeast Asia, Tibet, and India (Fig. 1). Several species were infected, including the bar-headed goose (*Anser indicus*), great black-headed gull (*Larus ichthyaetus*), and brown-headed gull (*Larus brunnicephalus*). Two key symptoms were noticed: abnormal neurological signs (tremor and opisthotonus) and diarrhea. Among the gross lesions, pancreatic necrosis was obvious and was confirmed by tissue section where extensive areas of lytic necrosis were seen, consistent with pathology observed in domestic geese and ducks infected with H5N1 AIV (*3*). Brain sections revealed glial cell infiltration, perivascular cuffing, and congestion in the blood vessels. Serological tests (*4*) from one bar-headed goose and one brown-headed gull confirmed the presence of high-titer antibody against H5N1 AIV.

Several H5N1 viruses were isolated from the viscera, brain, and swabs of the oropharynx and cloaca of sick and dead birds. Four of the isolates from different bird species were completely sequenced (*4*) and appeared to be closely related. None of the GenBank sequence data for known H5N1 AIV genomes completely matched our sequences, implying the viruses are reassortants. Five of the eight genomic segments (M, PA, PB1, PB2, and NS) were closely related to a Hong Kong 2004 isolate (A/peregrine falcon/HK/D0028/04) (*3*). We observed several characteristics in our four isolates: first, the sequence PQGERRRKKR/G, denoting multiple basic amino acids at the cleavage site of the hemagglutinin; second, a virulence island in the PB2 gene, E627K, first seen in Hong Kong in 1997 (*5*); and third, a deletion of 20 amino acids in neuramidase (amino acid positions 49 to 69), also associated with high virulence.

To test virulence, mice and chickens were infected with the BhGoose/QH/1/05 (*4*) isolate. All eight infected chickens died within 20 hours, and seven of eight infected mice died within 72 hours; the last died 96 hours post-infection. Earlier isolates taken from ducks in China were less virulent in mice and chickens (*6*). Hence we speculate that viruses might be emerging from reassortants that originate in birds overwintering in southeast Asia (*7*).

The occurrence of highly pathogenic H5N1 AIV infection in migrant waterfowl indicates that this virus has the potential to be a global threat: Lake Qinghaihu is a breeding center for migrant birds that congregate from southeast Asia, Siberia, Australia, and New Zealand.

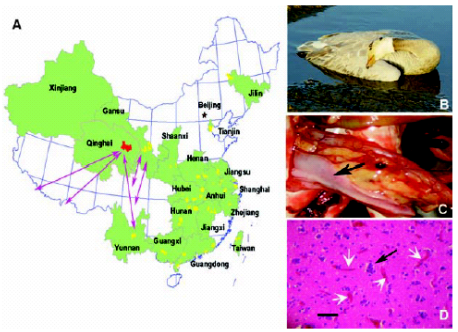


Fig. 1. (**A**) The reported H5N1 AIV prevalence sites during the 2004 outbreak in China are highlighted in yellow (*8*). Arrows indicate the migratory routes of the bar-headed goose (*A. indicus*) to Lake Qinghaihu. (**B**) A sick bar-headed goose showing typical opisthotonus before dying. (**C**) Bar-headed goose pancreas with pin-point necrotic lesions (arrow). (**D**) Microscopic lesions in bar-headed goose brain, showing congestion in the blood vessels (white arrows) and glial cell infiltration (black arrow). Hematoxylin and eosin ×25 (scale bar, 50 μm).

References and Notes

1. R. J. Webby, R. G. Webster, *Science* **302**, 1519 (2003).
2. K. Subbarao *et al.*, *Science* **279**, 393 (1998).
3. K. S. Li *et al.*, *Nature* **430**, 209 (2004).
4. Materials and methods are available as supporting material on *Science* Online.
5. M. Hatta *et al.*, *Science* **293**, 1840 (2001).
6. H. Chen *et al.*, *Proc. Natl. Acad. Sci. USA* **101**, 10452 (2004).
7. T. H. Cheng *et al.*, *Fauna Sinica: Aves* (Science Press, Beijing, 1979), vol. 2.
8. Available at www.china.com.cn/chinese/zhuanti/qlg/483177.htm
9. Supported by the Ministry of Science and Technology, PR China [grant nos. 2004BA519A29, 2004BA519A11, 2004BA519A10, and 2004BA519A50; National Basic Research Program (973) of China 2005CB523000], the Chinese Academy of Sciences (The President Fund and CAS Information Special grant no. INF105-SDB-3-A2), the State Forestry Administration of China, and the National Natural Sciences Foundation of China (grant nos. 30471282 and 30228025). Sequence data derived from this study were deposited in GenBank with accession no. DQ100542-DQ100573.

Supporting Online Material
www.sciencemag.org/cgi/content/full/1115273/DC1
Materials and Methods
Figs. S1 and S2
References and Notes

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10.1126/science.1115273
Include this information when citing this paper.

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Bar-headed goose

Are migratory wild birds victim or vector of HPAI H5N1?

ZOONOSES

In China's Backcountry, Tracking Lethal Bird Flu

Five years after flu devastated wild birds in China, researchers have confirmed one likely transmission route

QINGHAI LAKE, CHINA—The lake glitters like a sapphire under a blue sky as birds circle near the shore. On the rocky beach, two researchers are tying a GPS transmitter to the back of a small gray duck. They will track its migration by satellite, part of a series of investigations that began after highly pathogenic avian influenza (H5N1 subtype) first swept the region in 2005.

The studies aim to pinpoint the viral reservoir and the role that wild birds play in transmission. "The lake has attracted the whole world's researchers to keep a close eye on it," says He Yubang, vice director of Administration of Qinghai Lake Chinese National Nature Reserve. No reservoir has yet been found, but transmission routes have come into clearer focus.

The emergence of H5N1 was a disaster for wildlife and humans alike. Since 2003, H5N1 has killed 300 people, including 18 so far this year, according to the World Health Organization. More than 250 million infected domestic poultry have been culled, and thousands of wild birds have been felled. In 2005 alone, more than 6000 wild birds at Qinghai Lake died, "the single largest H5N1 wild bird mortality event that has ever occurred," says Scott Newman, an animal health officer for the UN Food and Agriculture Organization (FAO) in Rome.

H5N1 was first isolated in 1996 from a domestic goose in China's Guangdong Province. The next year, the virus spread to people in Hong Kong. After laying low, H5N1 flared in 2004 in several Asian nations. It kills about 60% those infected but does not spread easily from person to person. The virus has been held in check by poultry vaccination and better husbandry, but 16 countries, including China and Romania, have reported H5N1 outbreaks in poultry so far this year. A constant worry is that the virus will mutate into a more transmissible form among humans.

Because Qinghai Lake sits within the eastern portion of the Central Asian Flyway—which reaches from India and Bangladesh to Russia—some experts suspect it is a focal point of viral transmission. Others question whether wild birds play a major role in H5N1 dispersal, suggesting that the virus spreads primarily among poultry (*Science*, 21 October 2005, p. 426). To date, all human cases but one have been associated with exposure to poultry or found on farms. Researchers now believe that wild waterfowl on the eastern portion of the Central Asian Flyway help spread H5N1 into Mongolia each spring as they move across the Qinghai-Tibetan plateau to the north and east, says Newman. The role of wild waterfowl on the other major flyway is less certain.

Poultry production is on the rise in Asia, as are farming, trade, and the mixing of wild and domestic birds. "All of the mare increasing the opportunities for viral transmission and persistence," says Xiao Xiangming, a landscape ecologist and remote sensing expert at the University of Oklahoma, Norman.

Every summer, more than 100,000 migratory birds descend on Qinghai Lake, China's largest inland body of salt water. Half the birds that died here in 2005 were bar-headed geese (*Anser indicus*), says Lei Fu-Min, an ornithologist at the Institute of Zoology of the Chinese Academy of Sciences. Yan Baoping, chief engineer at the Computer Network Information Center in Beijing, led an academy team that set up a monitoring network after the die-off. The next year international scientists joined the effort. To date, the team led by FAO and the U.S. Geological Survey has tracked more than 525 waterfowl from 24 species in 11 countries.

In the past 5 years, the involvement of wild birds has become clearer, Lei says. "The H5N1 strains from wild birds that subsequently arrived in Asia and Eastern Europe were most like the H5N1 strains of Qinghai Lake," far from large poultry farms, he says. GPS data on migration paths are now being used for the first time to explore the relationships between different groups of birds and their interactions with domestic fowl, says Diann Prosser, a biologist at USGS's Patuxent Wildlife Research Center in Beltsville, Maryland. This year, she says, researchers learned that the majority of bar-headed geese tagged at Qinghai spend their winters in the Lhasa region of Tibet, south of the lake. These wintering grounds have domestic poultry and captive bar-headed goose farms—and H5N1 outbreaks have been reported there, suggesting a path for the virus to move from captive to wild birds.

Southeast of Lhasa, the ruddy shelduck may help explain the virus's spread, says John Takekawa, an ecologist at USGS's Western Ecological Research Center. In autumn and winter the ducks gather at Poyang Lake in the lower reaches of the Yangtze River within the East Asia Flyway (*Science*, 23 October 2009, p. 508). Qinghai strains can be traced to one early strain from Poyang based on the genomic analysis, Lei said. But recent work suggests that the viral reservoir may lie farther to the north, in Siberia—an area shared by both major Asian flyways—or that another as-yet-unstudied migratory bird may be carrying the virus from lake to lake. Since 2006, Xiao has led an international team to develop an early-warning system for H5N1 in Asia, focusing on agricultural and ecological risk factors.

Researchers need a better understanding of wild bird distribution, habitat use, and daily movements, Newman says. And the human role—including population growth and urbanization—must be better accounted for, says Takekawa. Why some people exposed to the virus become infected and others do not "is still an unsolved question," says Shu Yuelong, director of the National Influenza Center of the Chinese Center for Disease Control and Prevention. China has launched a nationwide monitoring network to check poultry markets for H5N1. That's a good start, but what's needed is a global network, says Shu. It must get started now, he says, "without delay." **–LI JIAO**

Li Jiao is a writer in Beijing.

Mixing bowl. Scientists track birds entering and leaving Qinghai Lake with GPS transmitters.

CREDITS (TOP TO BOTTOM): HOU YUANSHENG, YANG TAO/COMPUTER NETWORK INFORMATION CENTER

Can wild birds carry HPAI H5N1 along migratory pathways?

GPS-transmitter to track wild bird migration

Satellite telemetry of waterfowl

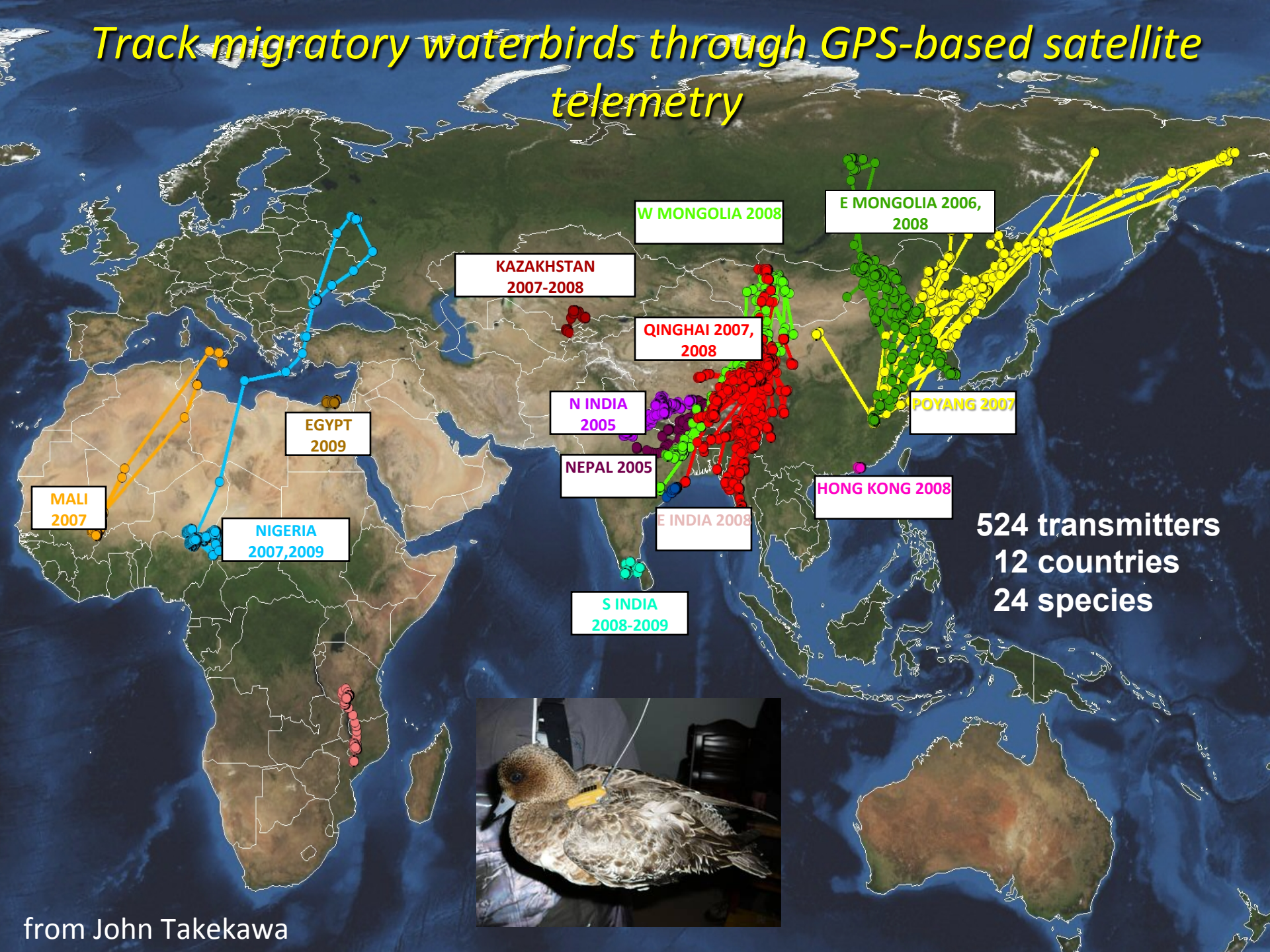
Capture and mark waterfowl to study their local movement, habitat use, and migration in relation to potential HAPI H5N1 spread

Qinghai Lake, China

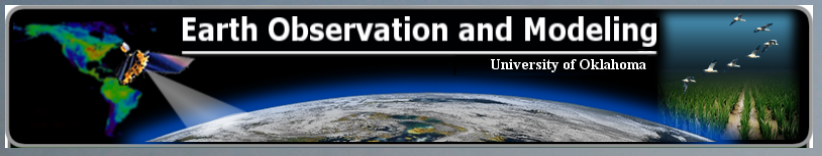
Ruddy shelduck (*Tadorna ferruginea*)

Bar-headed geese (*Anser indicus*)

Track migratory waterbirds through GPS-based satellite telemetry



from John Takekawa



Role of domestic ducks in avian influenza A (H5N1)

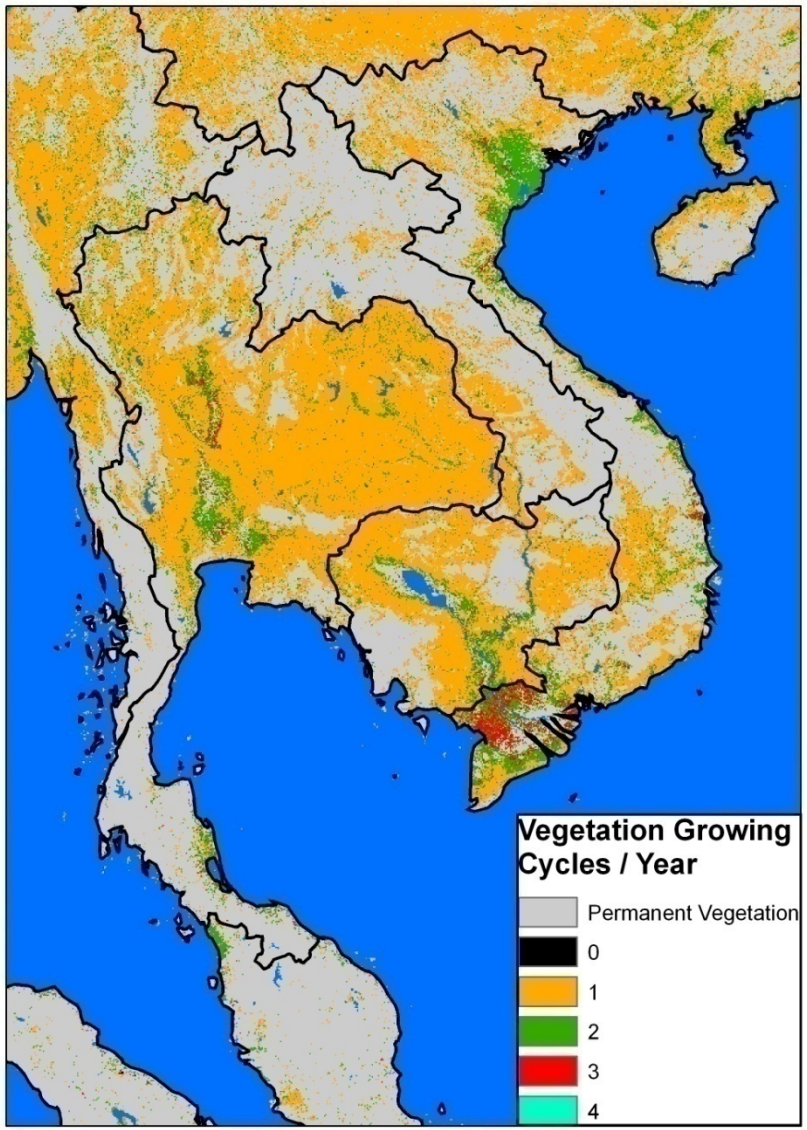
There are lots of domestic free-range ducks in post-harvested paddy rice fields.

-- Healthy ducks may carry H5N1 virus

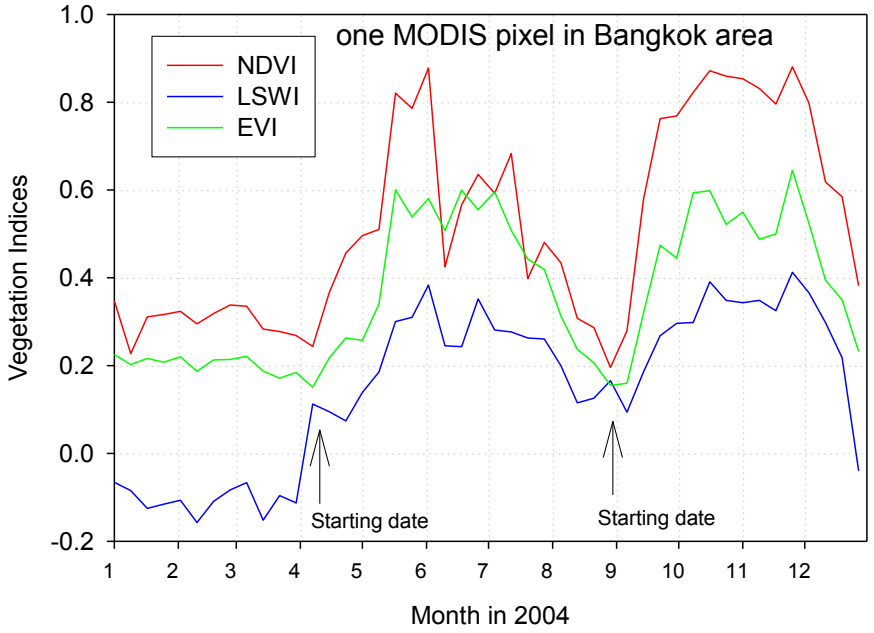
GPS receivers to track free-grazing ducks

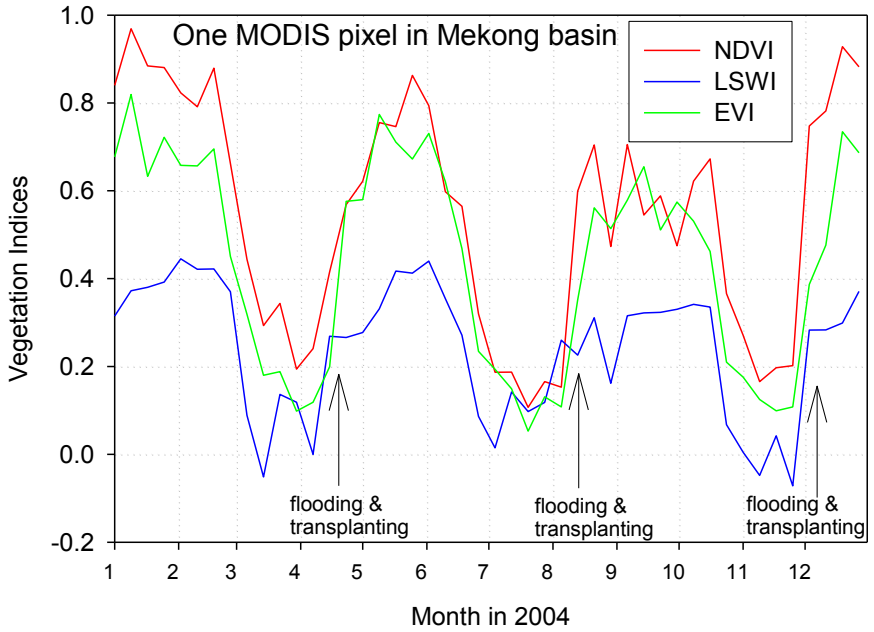
Domestic ducks use both paddy rice fields and natural wetlands

Mapping Croplands and Wetlands

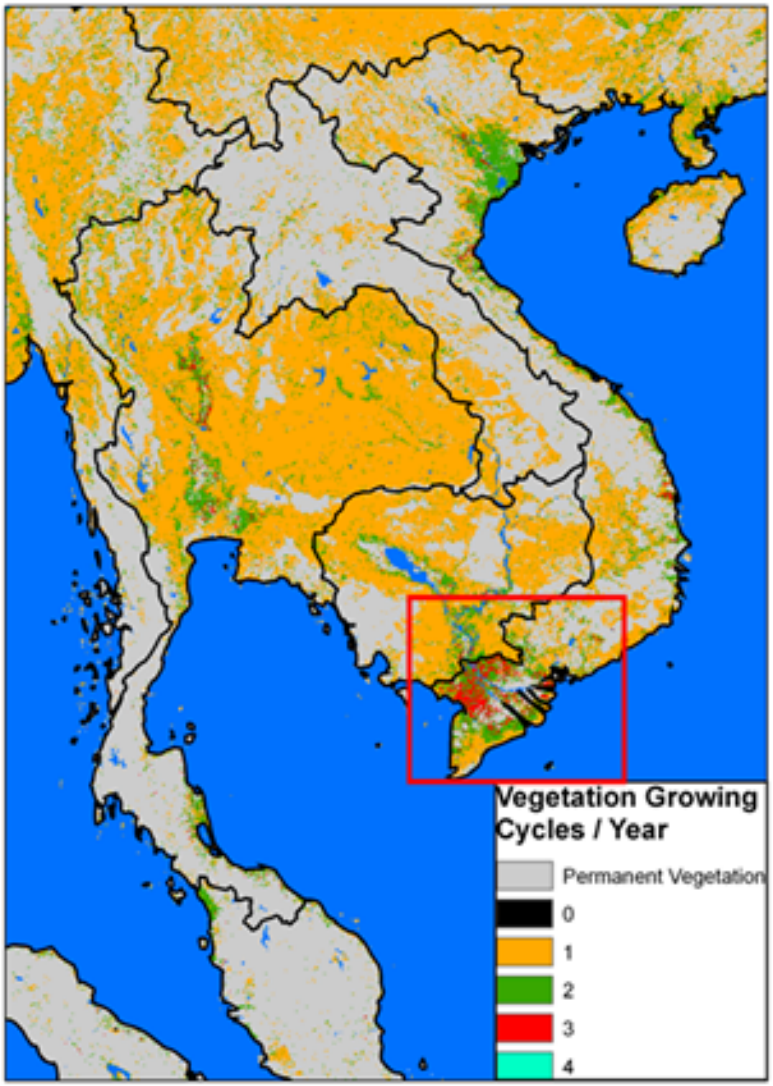


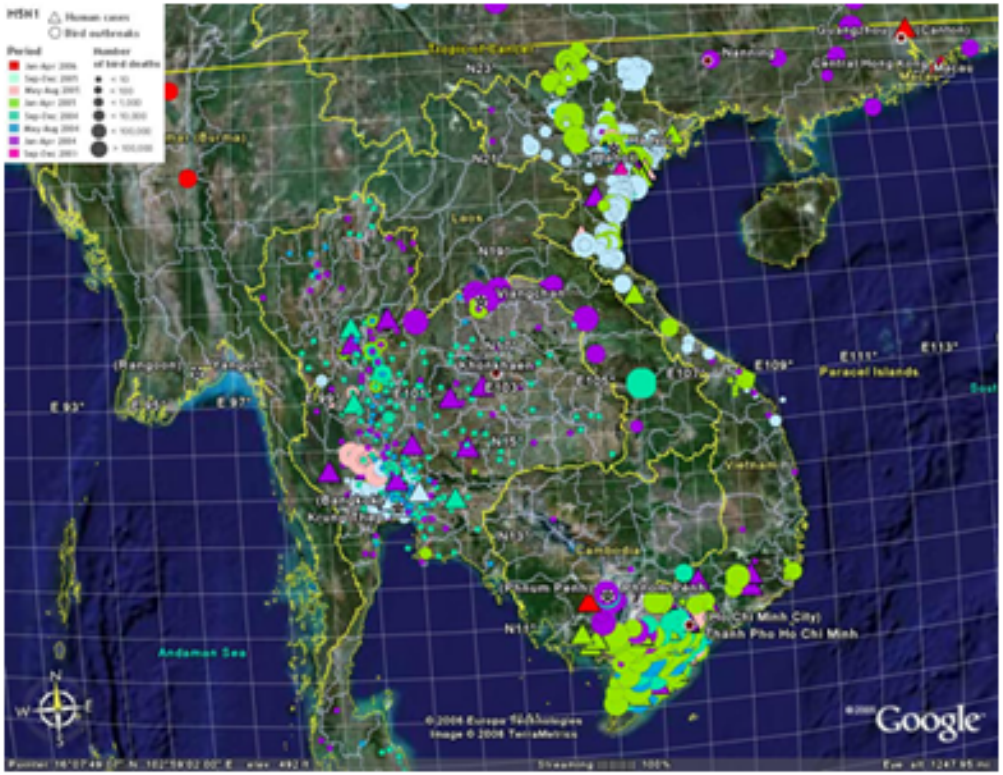
Cropping Intensity map in 2004





Epidemiology - Identify hot-spots and hot-times of H5N1 HPAI





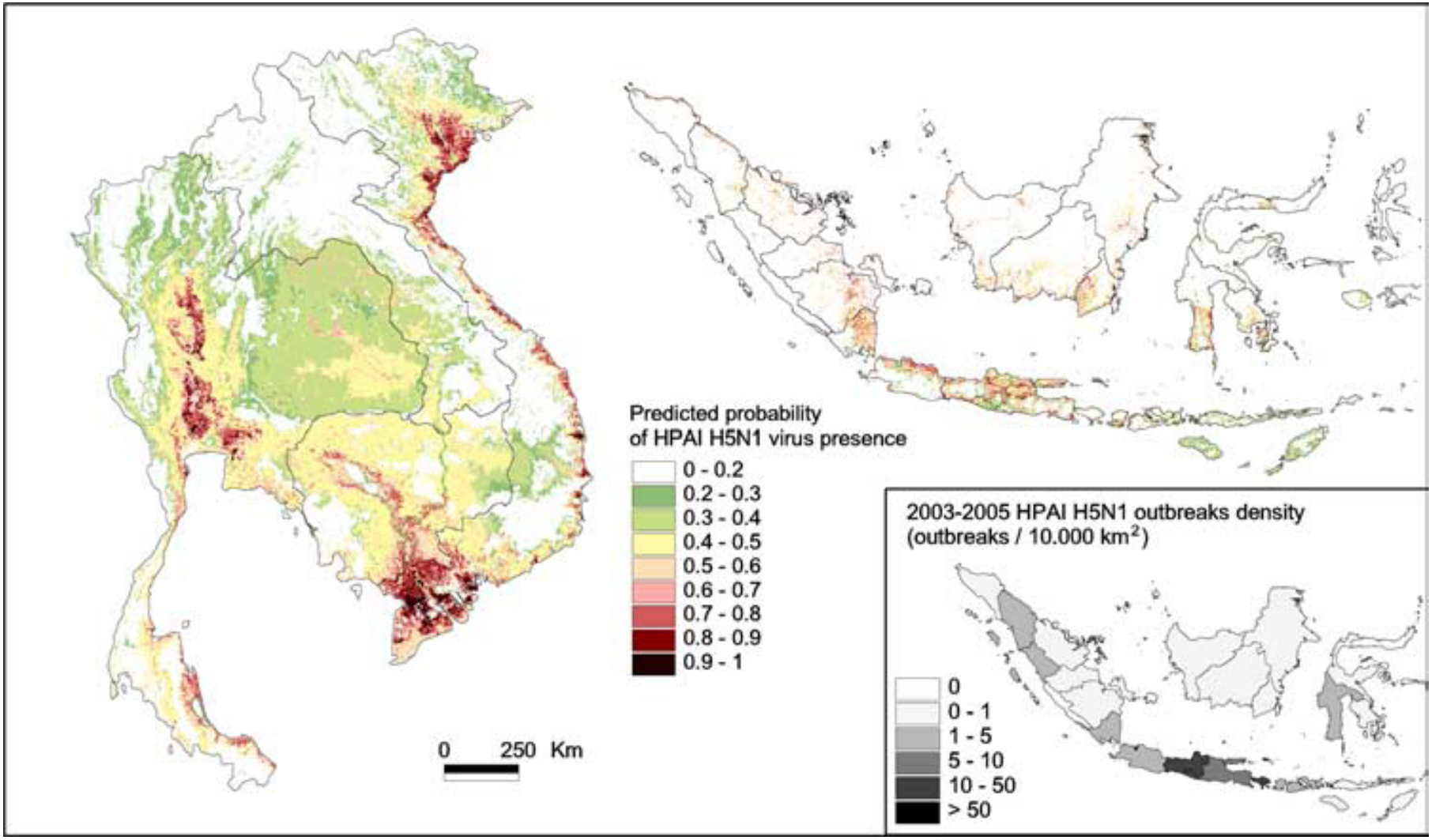
Screenshot taken in Google Earth(TM)

Agriculture – bird flu

These figures show that H5N1 outbreaks in Thailand and Vietnam were concentrated in those area with multiple cropping systems, in particular, multiple paddy rice system.

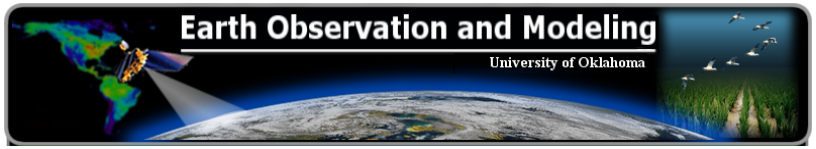
Traditionally, free-grazing duck system is closely coupled with multiple paddy rice cultivation, which provides foods and water year-around for ducks. The paddy rice – duck system dominate much of Southeast Asia countries.

Risk assessment of infectious diseases through spatial modeling



Prediction of HPAI H5N1 virus relative risk of presence in Thailand, Laos, Cambodia, and Vietnam.

Spatial epidemiological model input data: chicken density, duck density, cropping intensity, human population, and elevation(from Gilbert and Xiao, et al., 2008, PNAS)



Decision support system in FAO

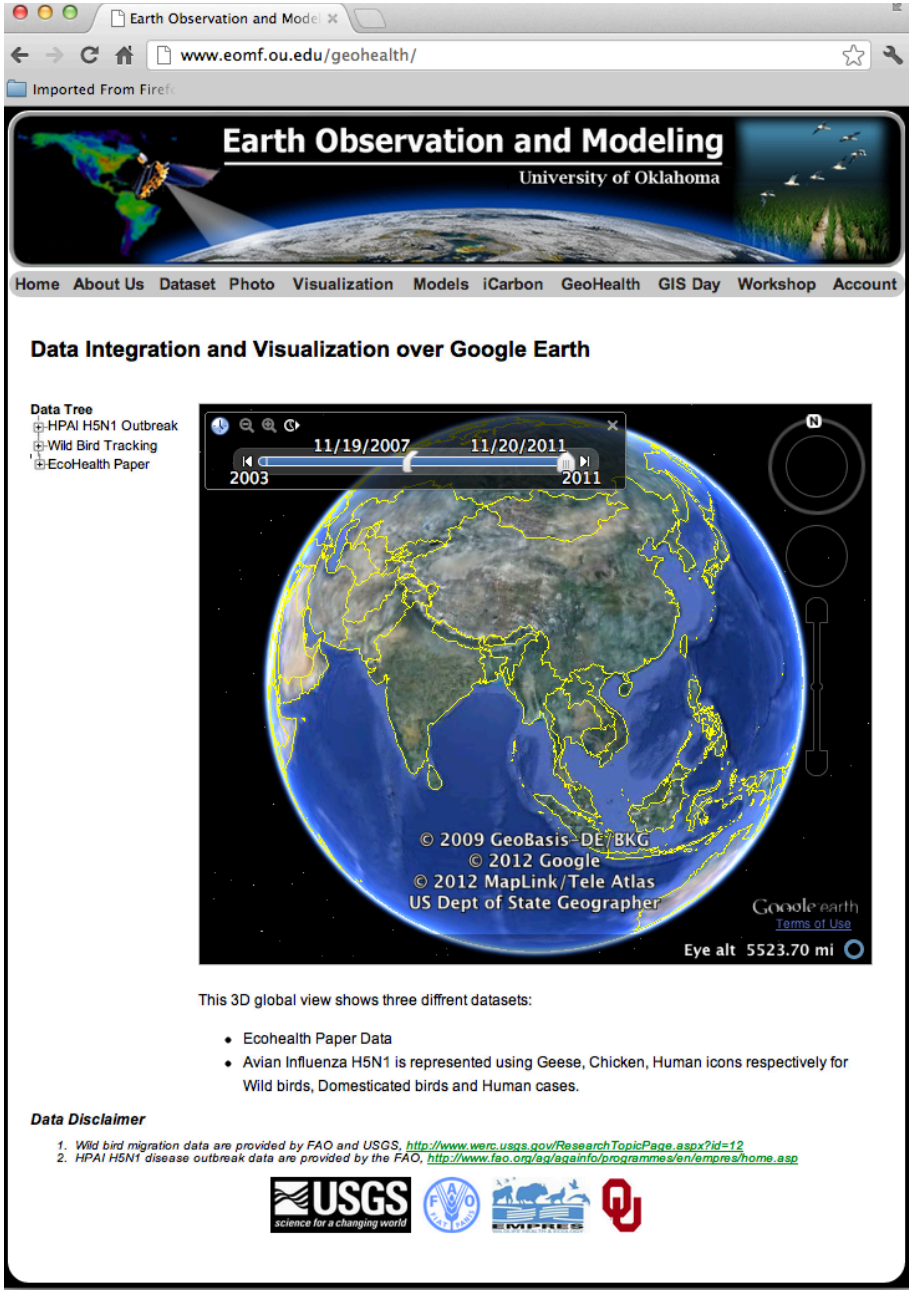
Food & Agriculture Organization of the United Nations (FAO)

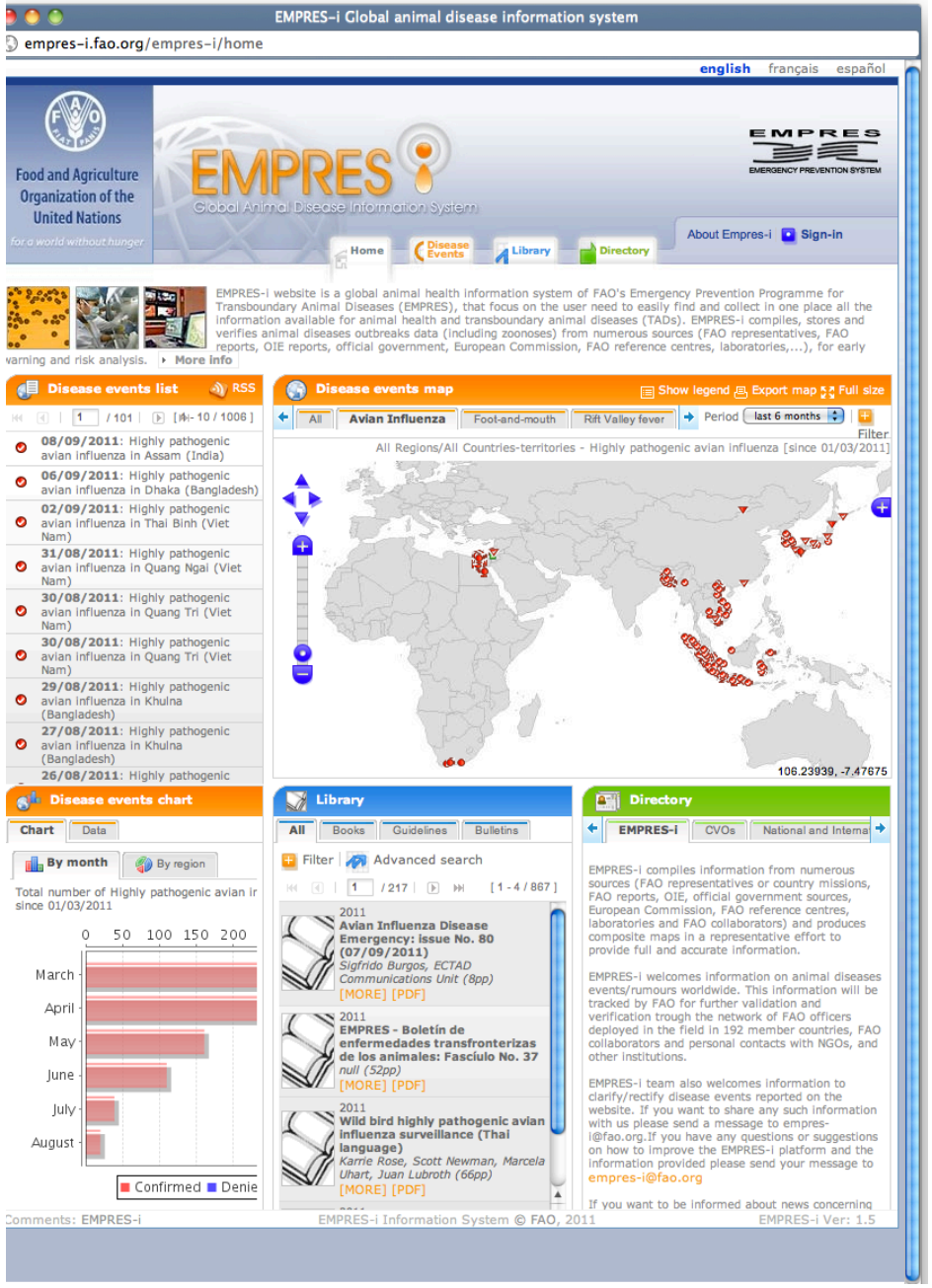
Animal Production and Health Division

The Emergency Prevention System (EMPRES) for Priority Animal and Plant Pest and Diseases

Crisis Management Center

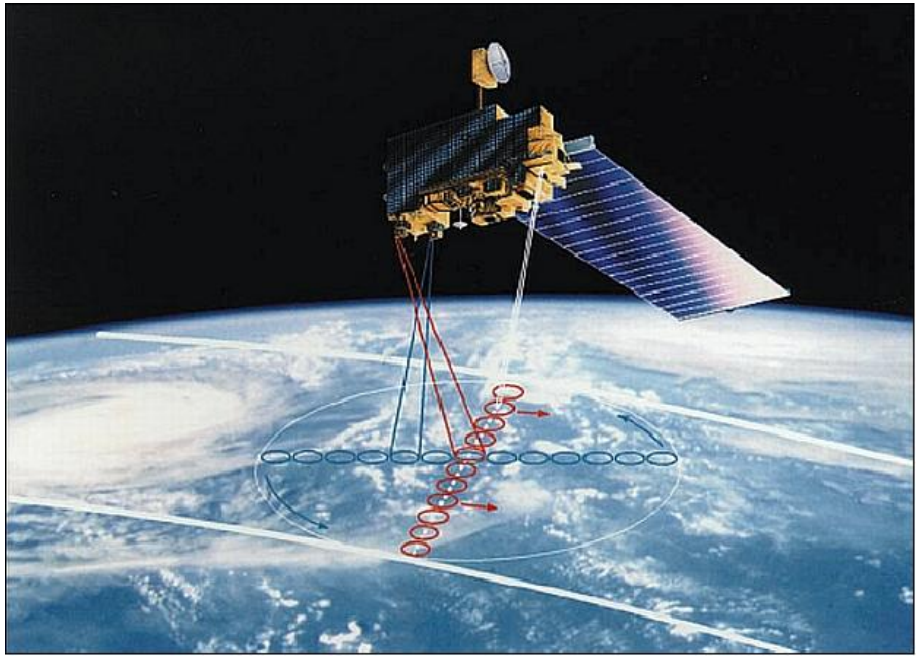
To develop the OU EOMF data portal and link it with FAO EPRES-i data portal





Project Accomplishment & Deliverable

1. Data portal at the Earth Observation and Modeling Facility
2. GeoHealth module
3. Geo-Referenced Field Photo Library
4. iPhone App for field photos and metadata

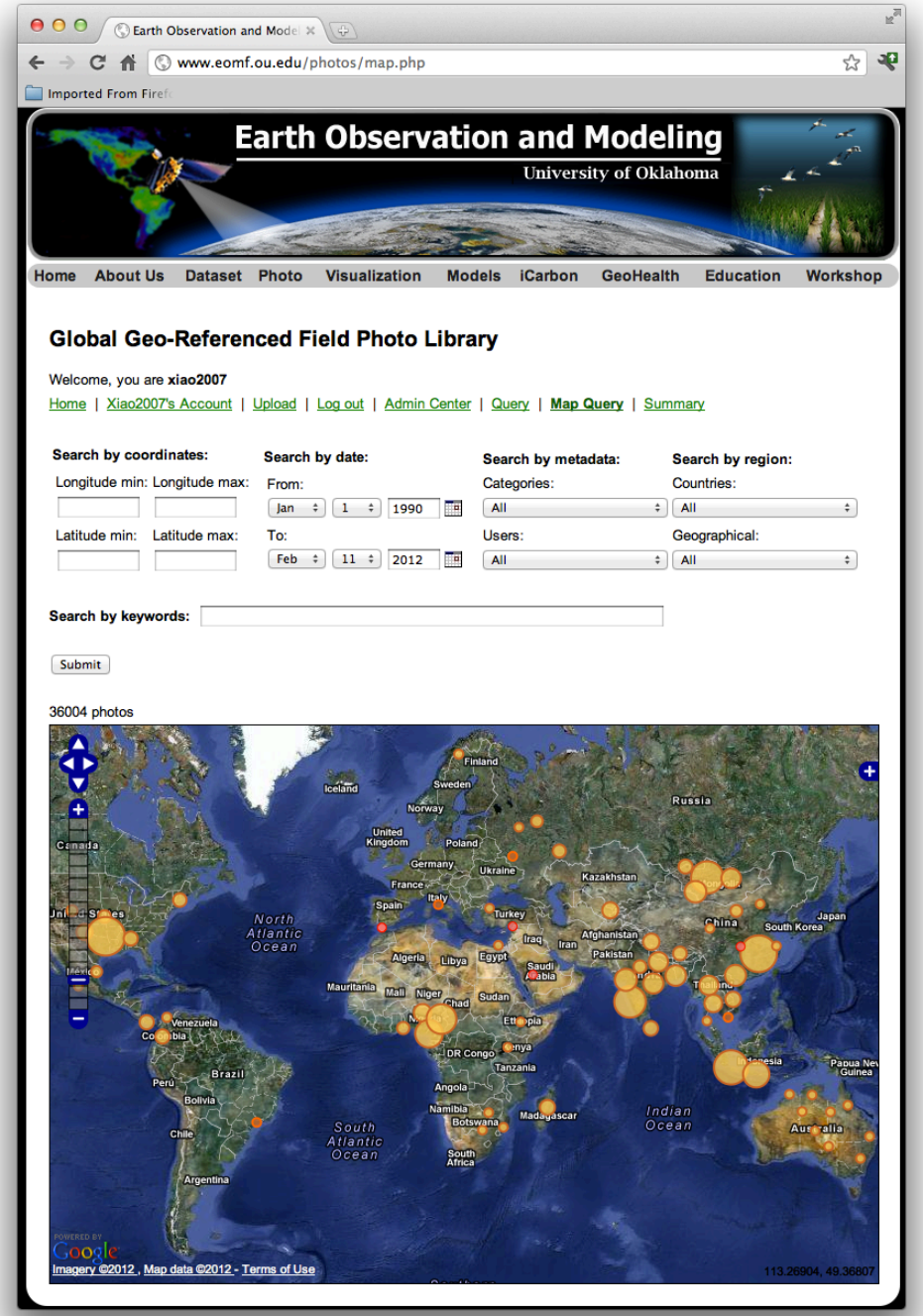


Geo-Referenced Field Photo Library at the University of Oklahoma (http://www.eomf.ou.edu/photos)

A citizen science data portal for sharing and archiving geo-tagged field photos of cropland, rangeland, forest, wetland, water body, wildlife, village, urban, fire, drought and flood in the world. All photos are linked with MODIS satellite images.

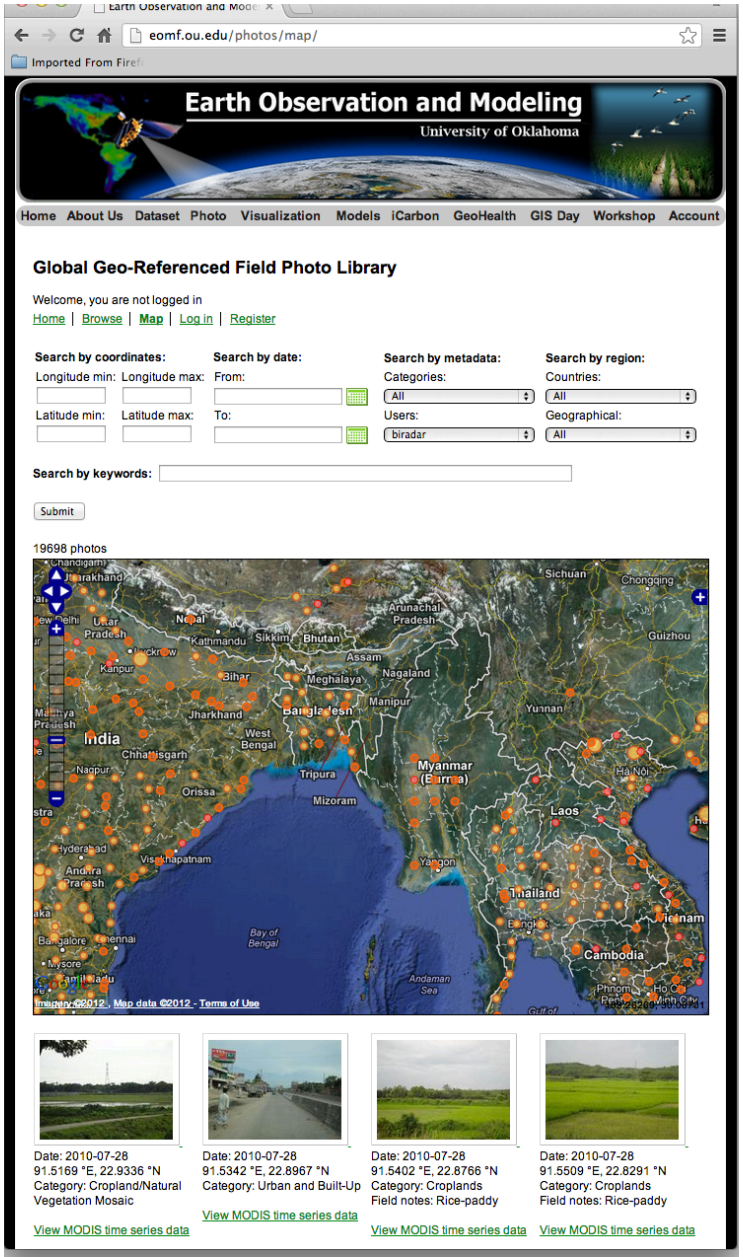
GPS camera

smartphone

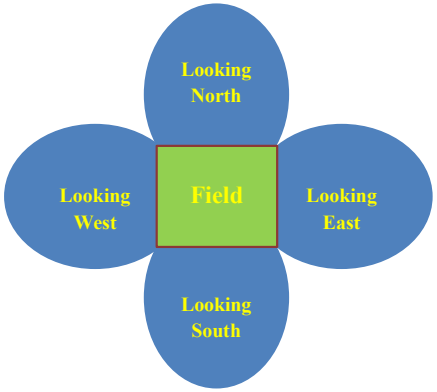


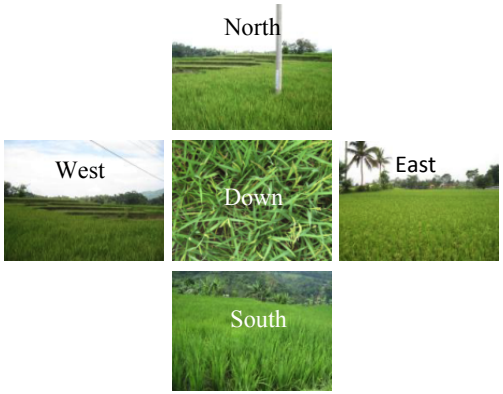
Share your field photos, show your footprint and support monitoring of our planet Earth

Geo-Referenced Field Photo Library

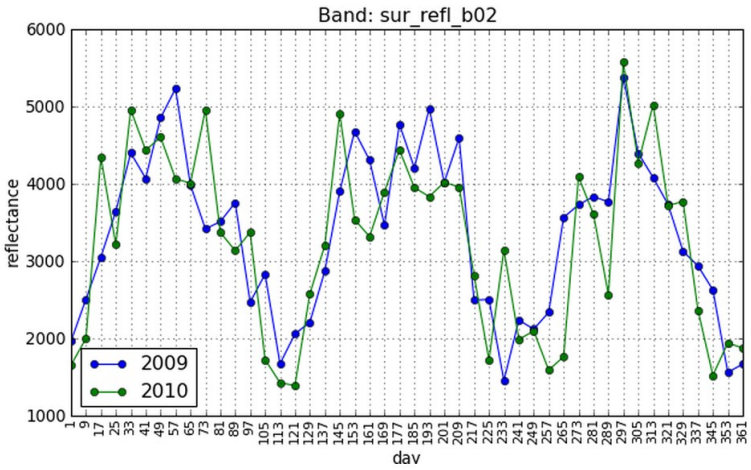


Protocol for taking photos in the field

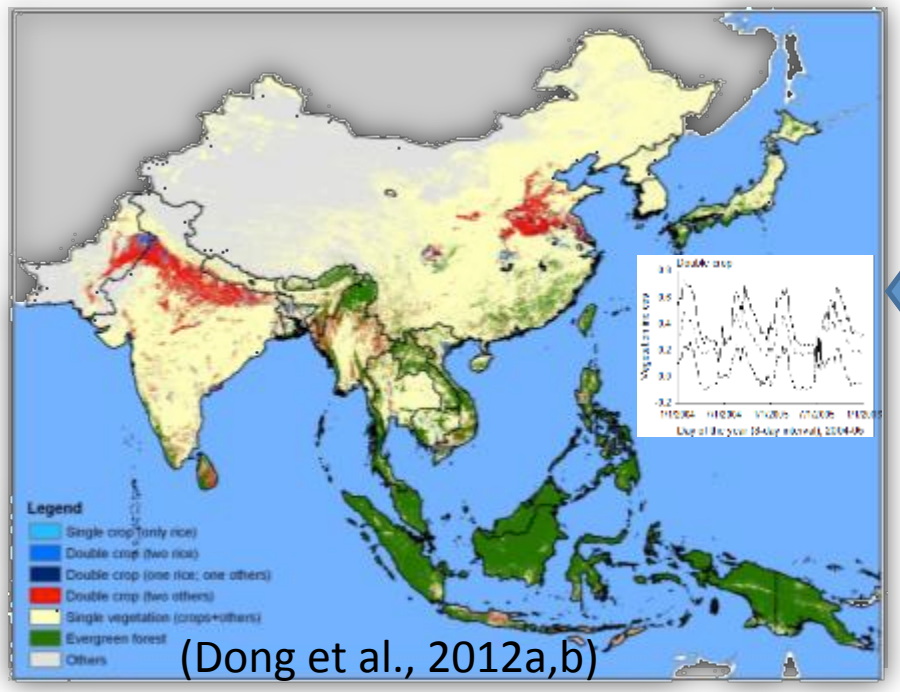




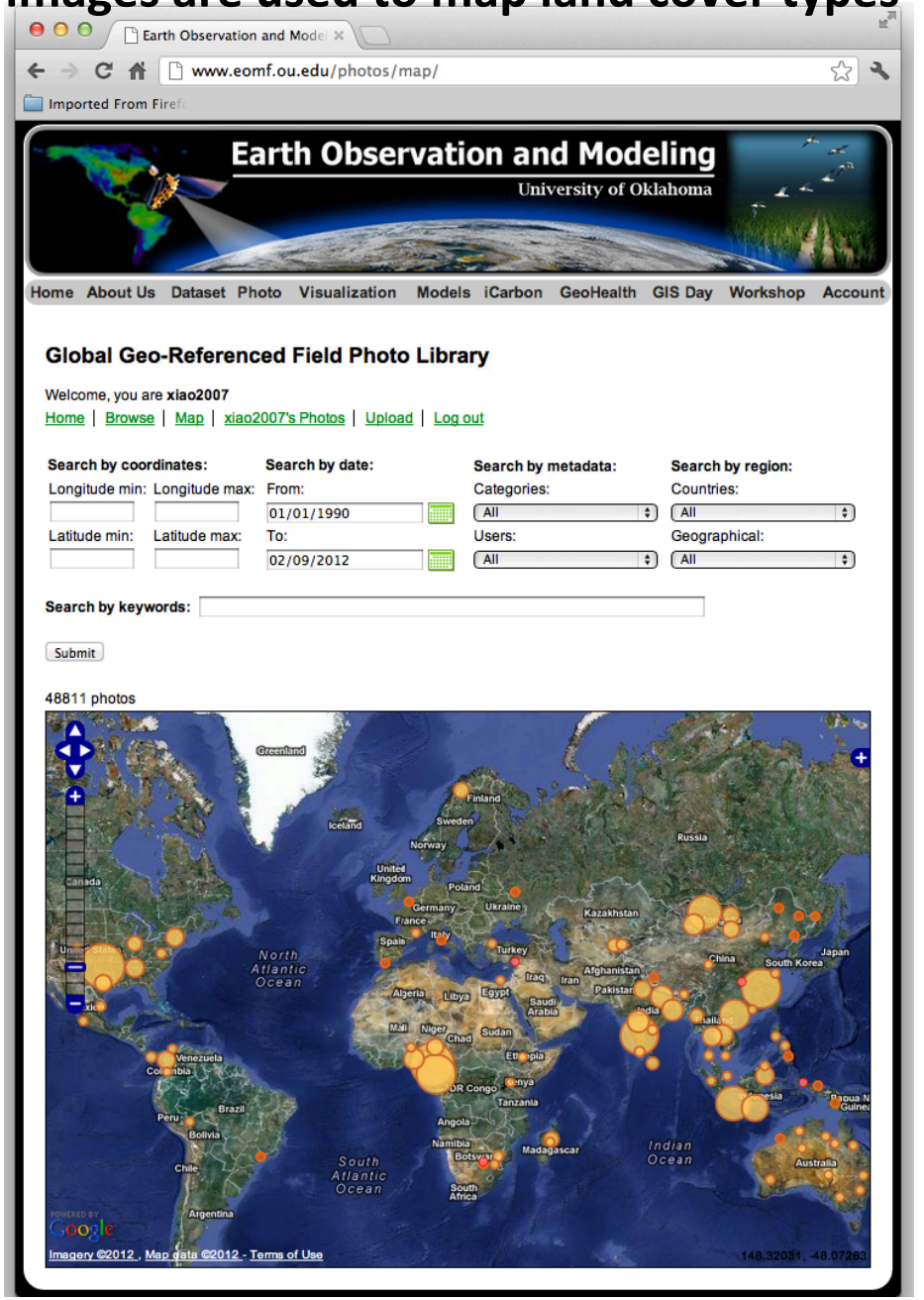
Individual photos are linked with time series MODIS data (2000-present)

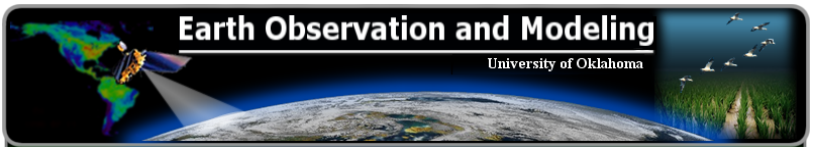


Geo-referenced field photos & satellite images are used to map land cover types



(Dong et al., 2012a,b)





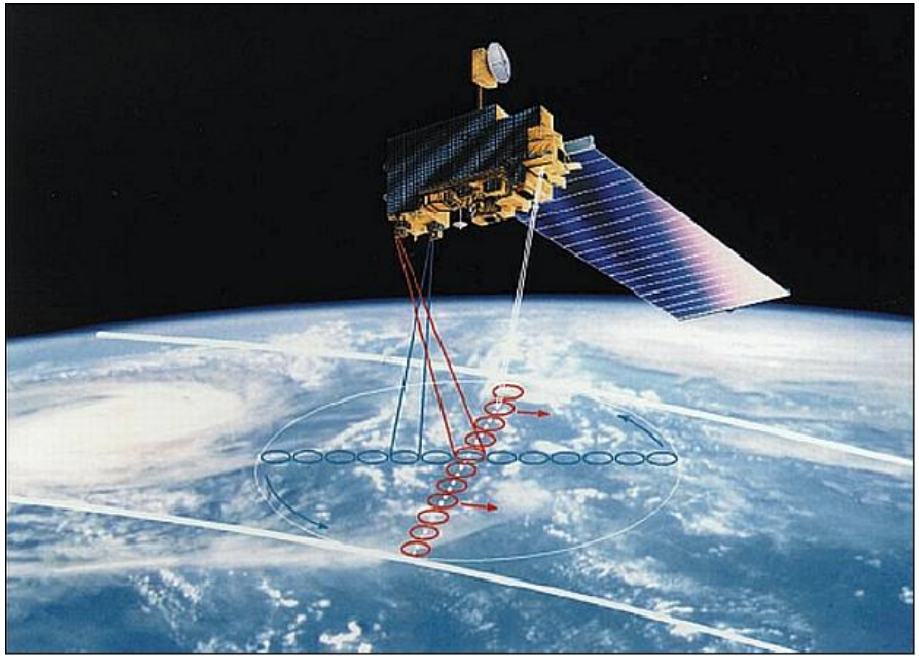
Community Remote Sensing and Citizen Science

Connecting Citizen Science and Community Remote Sensing

Global MODIS datasets (2000 – present)

Global Geo-Referenced Field Photo Library

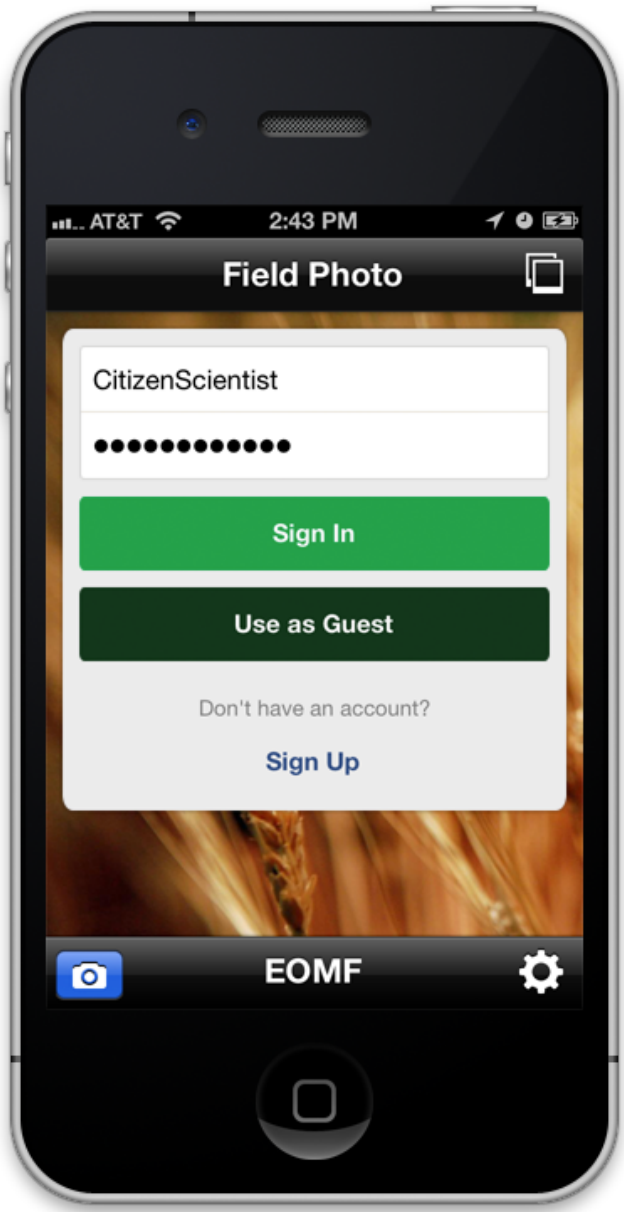
Millions of GPS smartphones and educated users



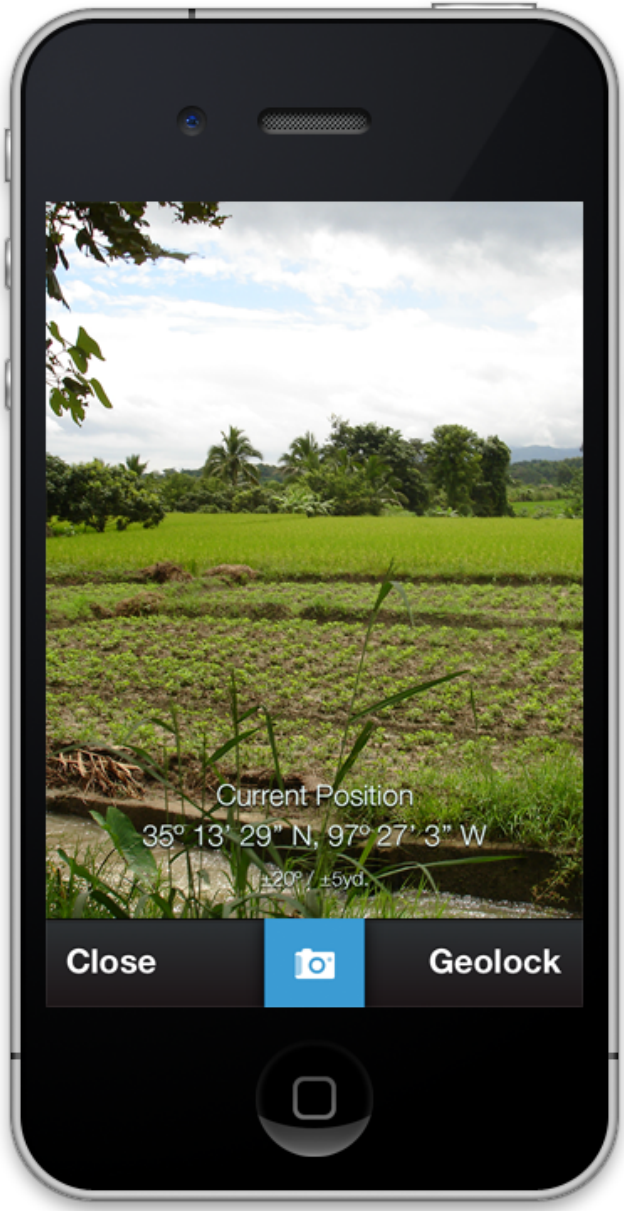
Earth Observation and Modeling
University of Oklahoma

Smartphone App (iPhone) - *FieldPhoto*

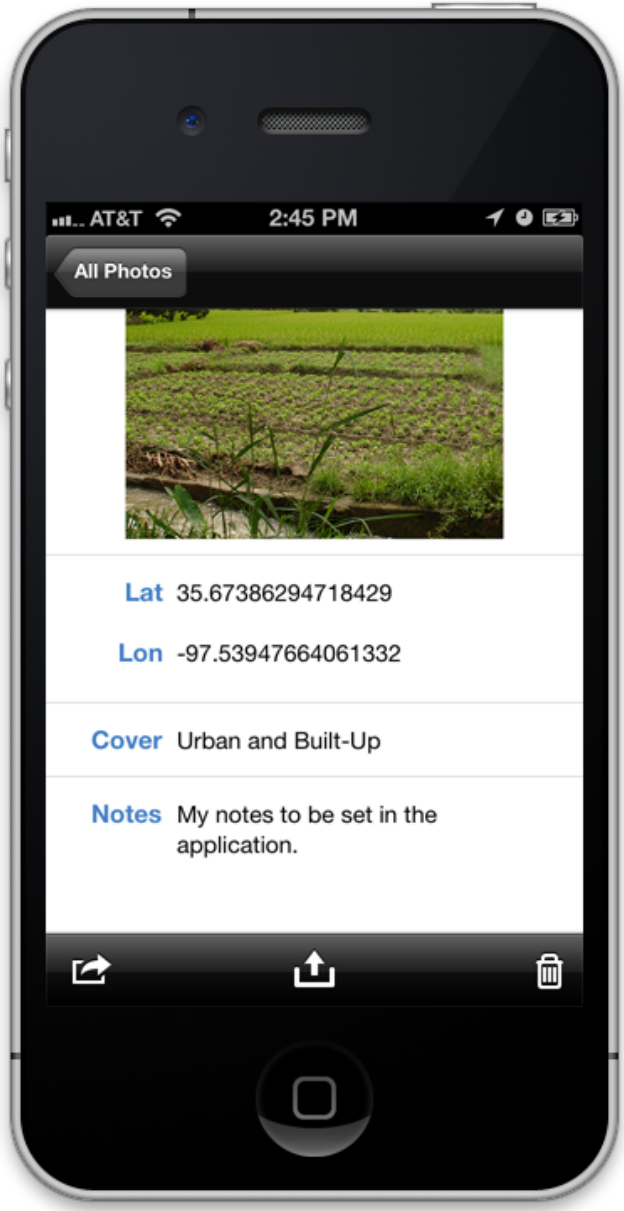
Launch App & sign-In



Take photo in the field



Enter meta data



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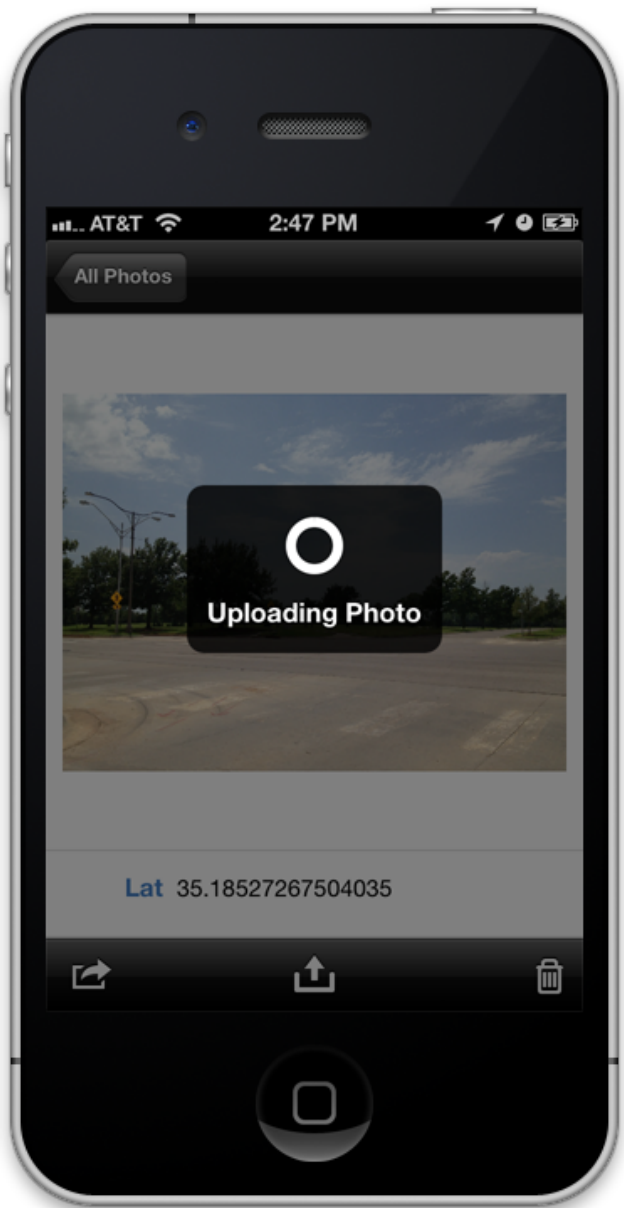
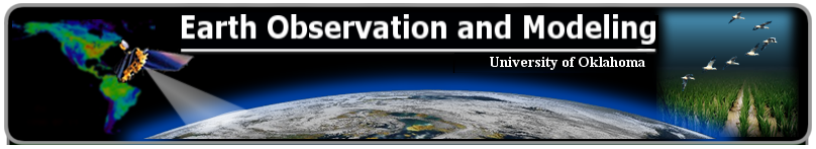
Smartphone App (iPhone) -- *FieldPhoto*

Field photo album

Share field photos

Upload field photos



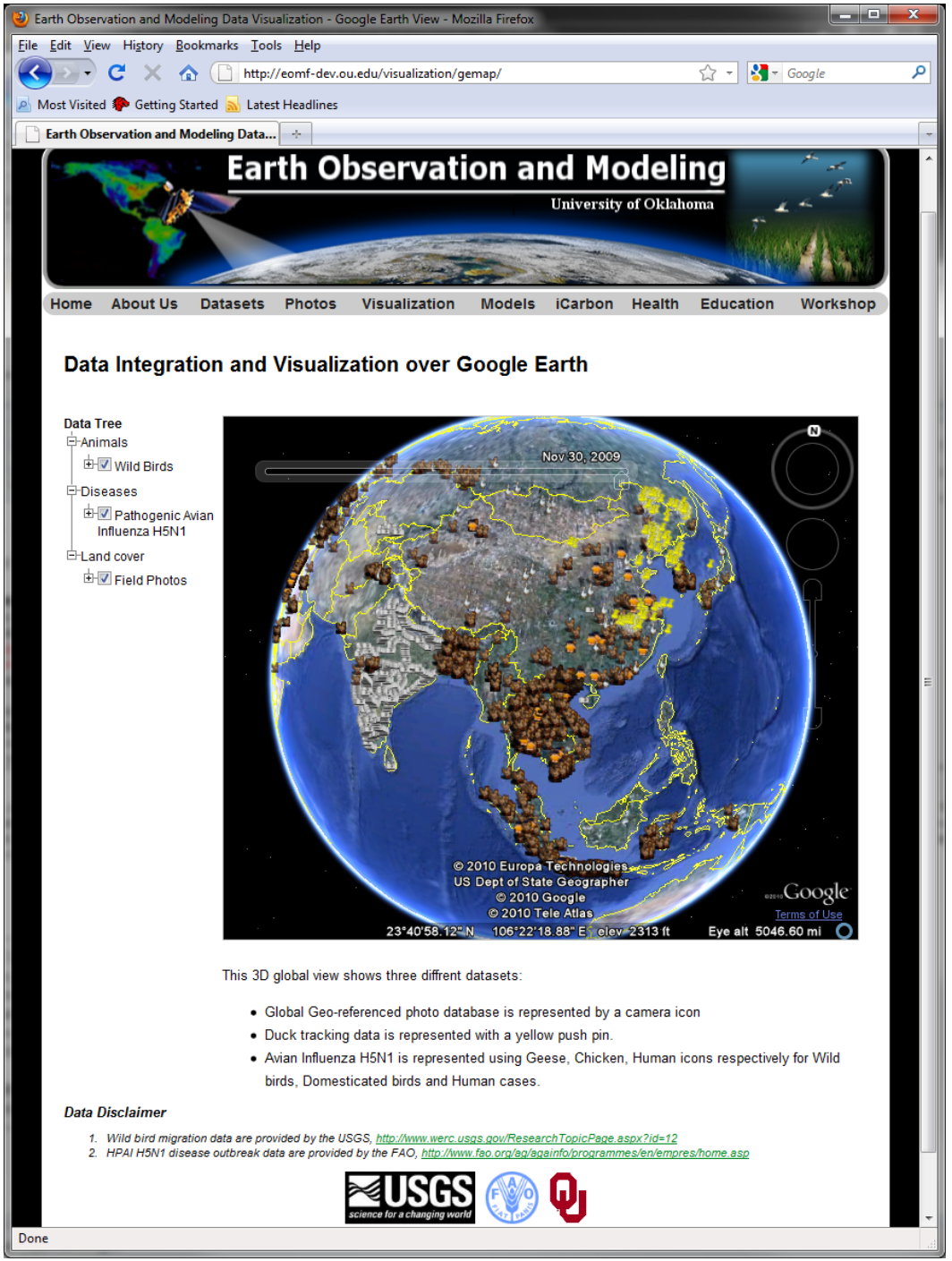


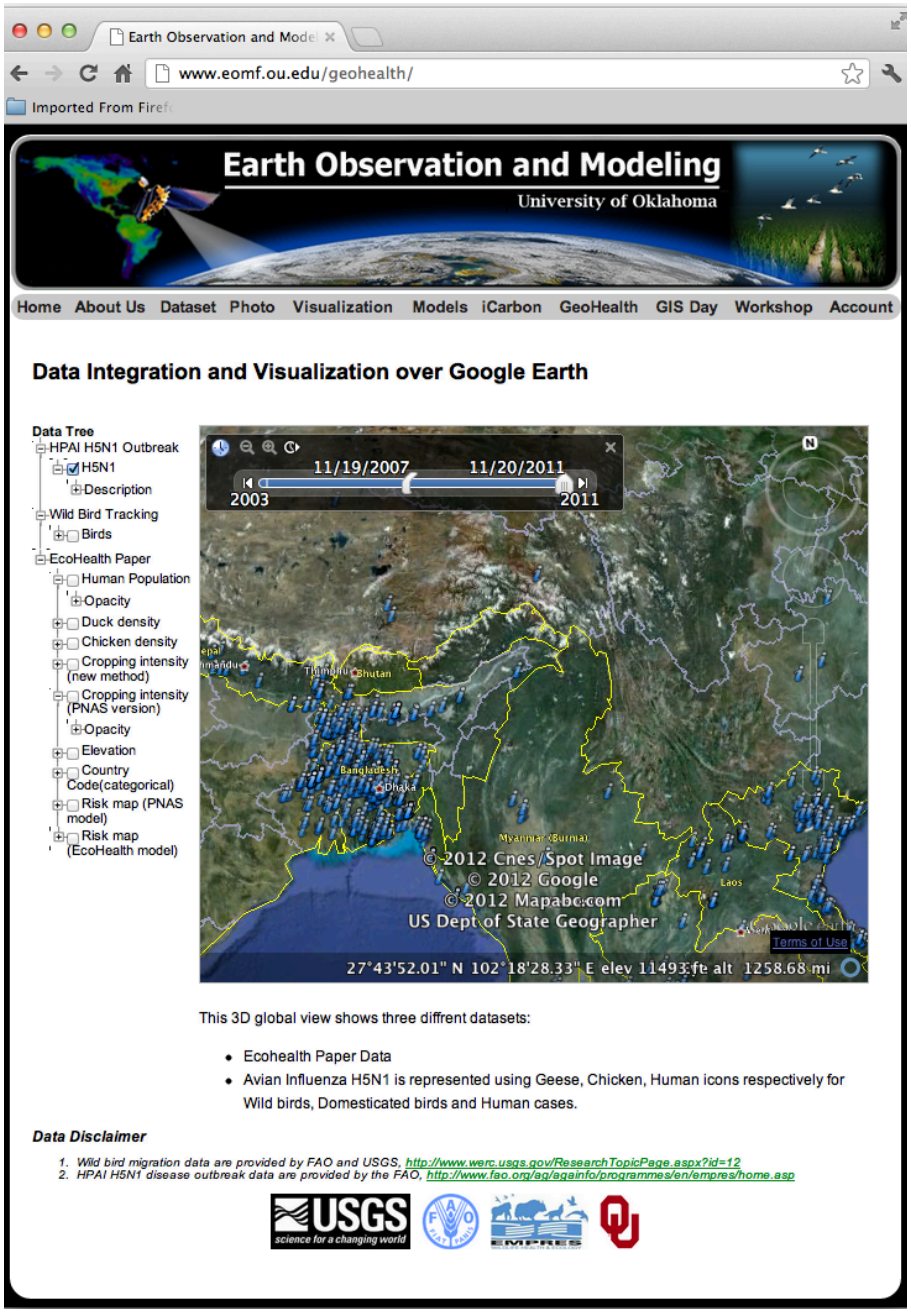
GeoHealth module

- Informatics approach to integrate disparate sources of datasets
- Data visualization

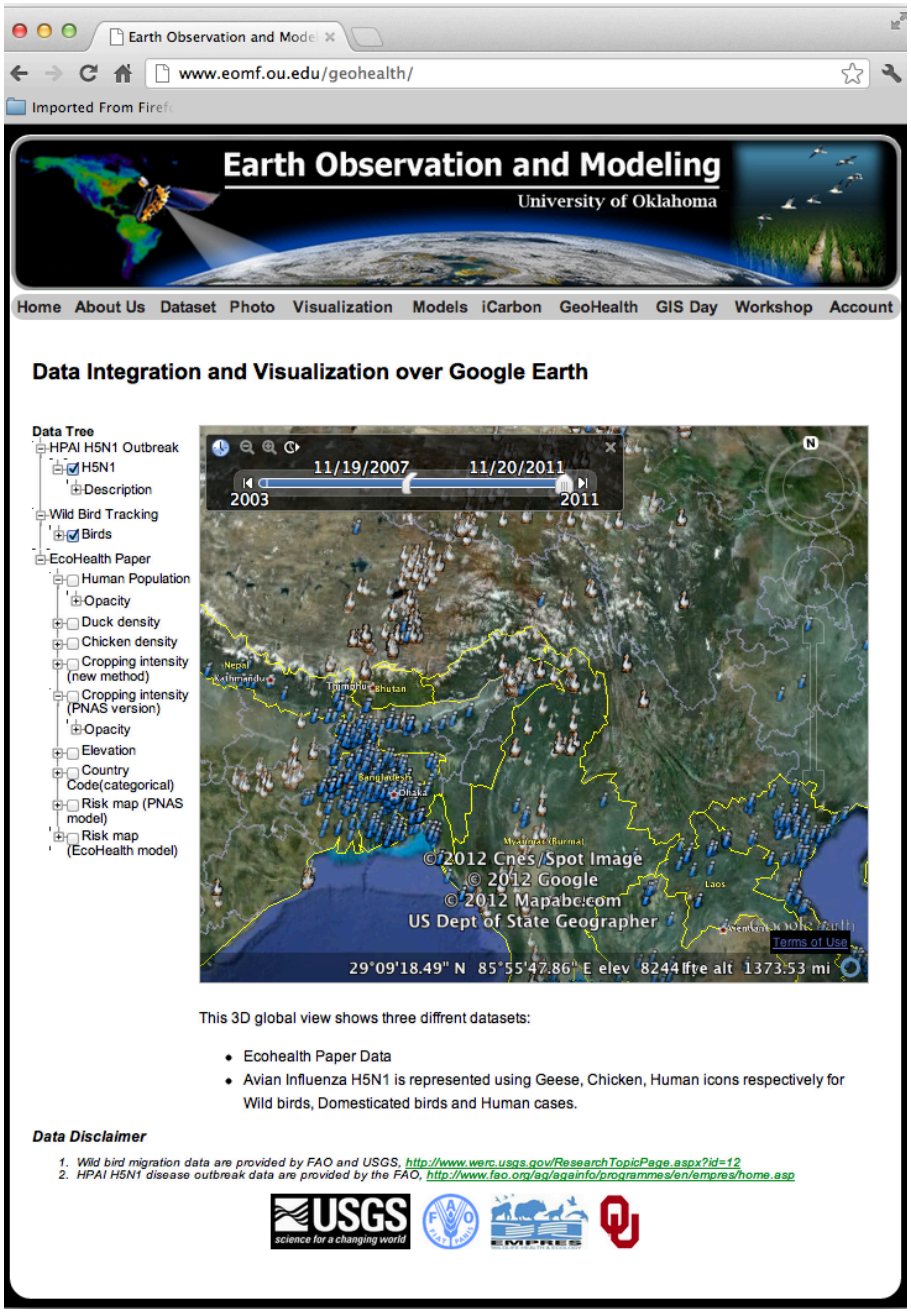
Disparate datasets

- Highly pathogenic avian influenza H5N1 data
- Human population
- Poultry, pigs,
- Satellite telemetry of wild birds
  - Wild bird migration
- Satellite-based mapping of agricultural land use - paddy rice
- AIV surveillance data (GenBank, OpenFlu)
- Market chain data
- Geo-tagged field photos
- Weather and climate

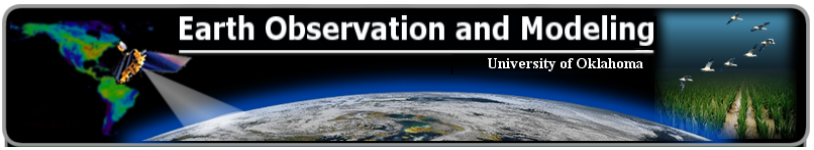




H5N1 outbreak cases



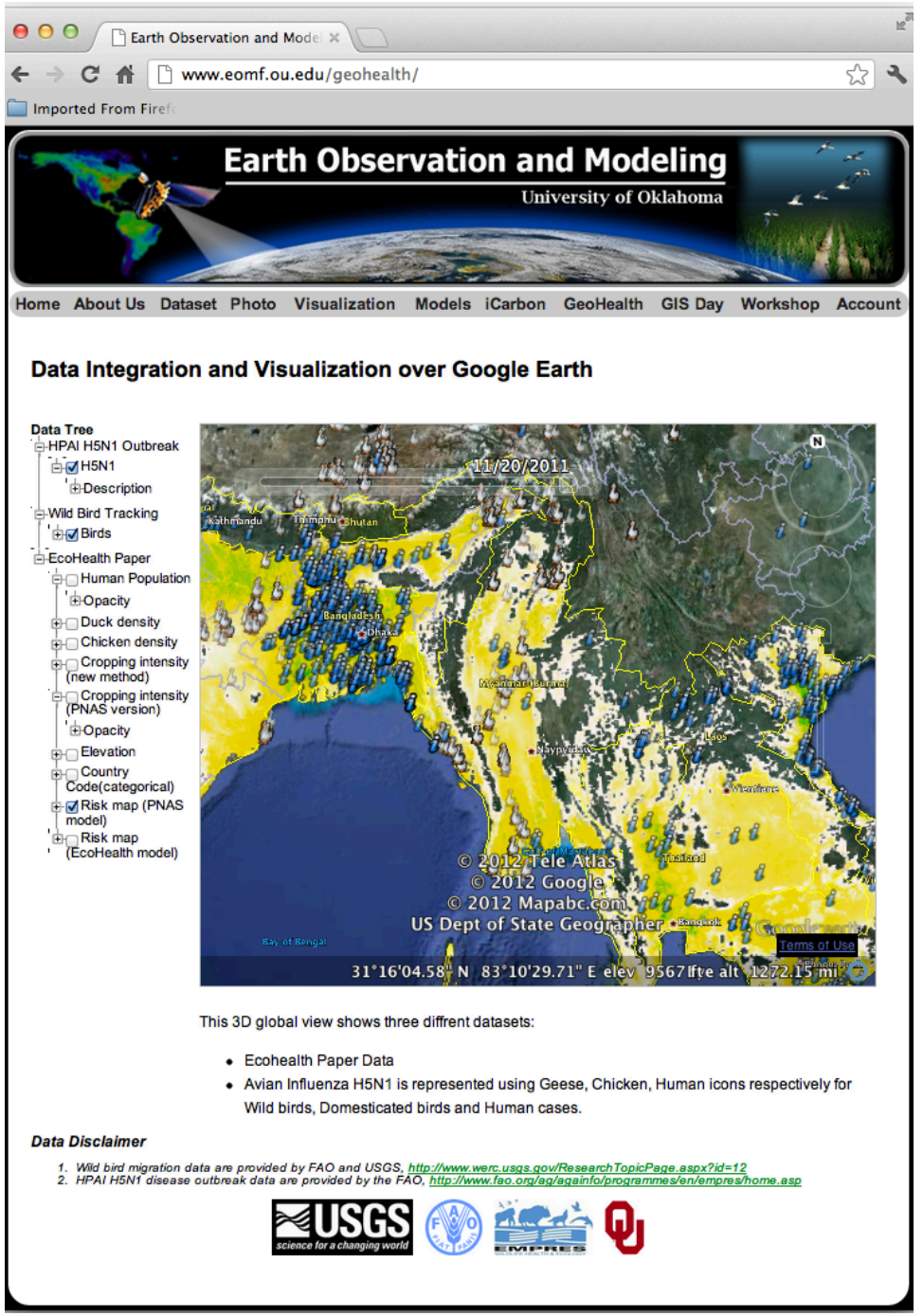
H5N1 cases & wild bird migration data



GeoHealth module

Dynamic overlay of geospatial datasets

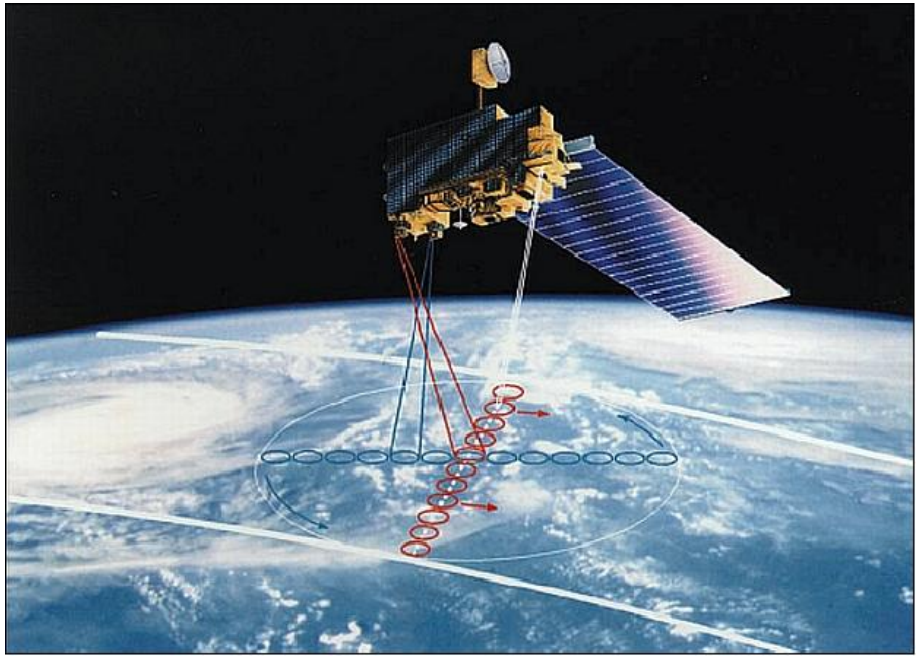
1. H5N1 outbreak case data,
2. Wild bird migration data,
3. Agro-ecological risk factors,
4. Risk maps from spatial epidemiological models



Broader Impacts of the Project

1. Community remote sensing and citizen science

2. Campus-wide GIS Day 2012, 2013 at the University of Oklahoma

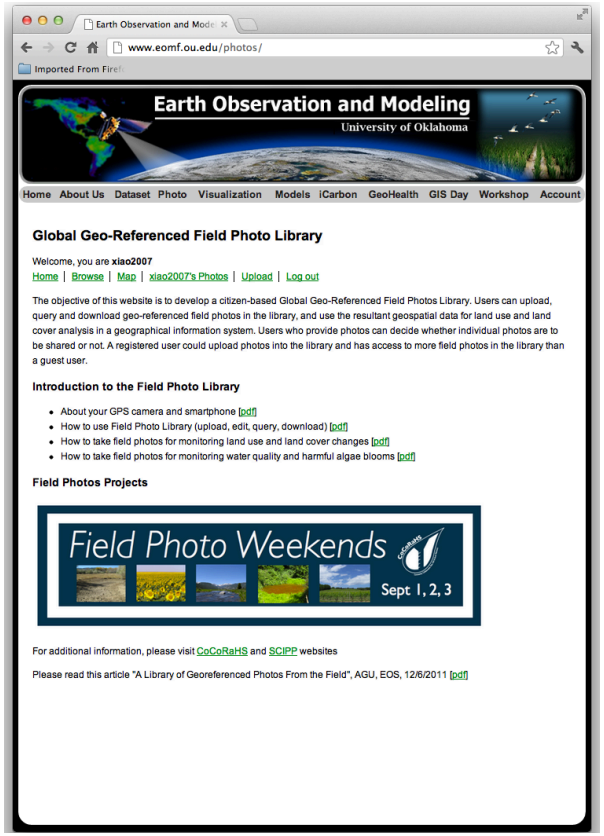


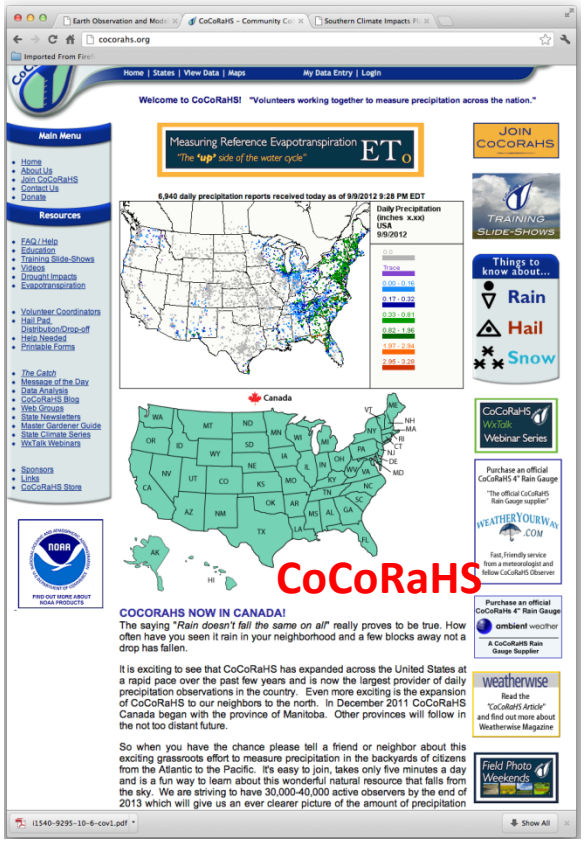
The Geo-Referenced Field Photo Library is now used by other projects.

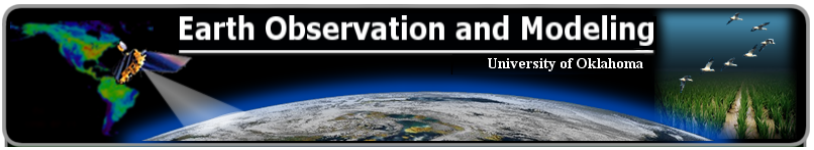
Field Photo Weekends

CoCoRaHS - 15,000 volunteers who regularly collect *in-situ* data of precipitation
SCIPP - climate impact research (drought, flood)
EOMF - web data portal and service

Partnership among scientists, stakeholders and citizen scientists







What is next?

Since highly pathogenic avian influenza A(H5N1) outbreaks in China and Southeast Asia in 2003, our disease ecology research in avian influenza has been supported by FAO (2005-2006), NIH Fogarty International Center (2006-2013, R01) and NIH National Institute of Allergy and Infectious Diseases (NIAID, 2013-2017, R01).

This NASA-funded feasibility study project has demonstrated the potential of Earth observation data and satellite telemetry data in understanding and modeling transmission dynamics and spillover risk of avian influenza at the human-animal interface.

Full integration of the EOMF data portal with the FAO EMPRES-I, with additional support in the future from NASA and other funding agencies, will better address the diverse needs of researchers, stakeholders, citizens, and decision makers for pandemic preparedness of avian influenza and other zoonotic infectious diseases.

Thank you

http://www.eomf.ou.edu

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